

In collaboration with



Watermark Numerical Computing



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**Ordine degli Ingegneri di Milano**  
organizes the

**Practical Course**  
(in English and Italian)  
**Groundwater**  
**Model Calibration**  
**using PEST**

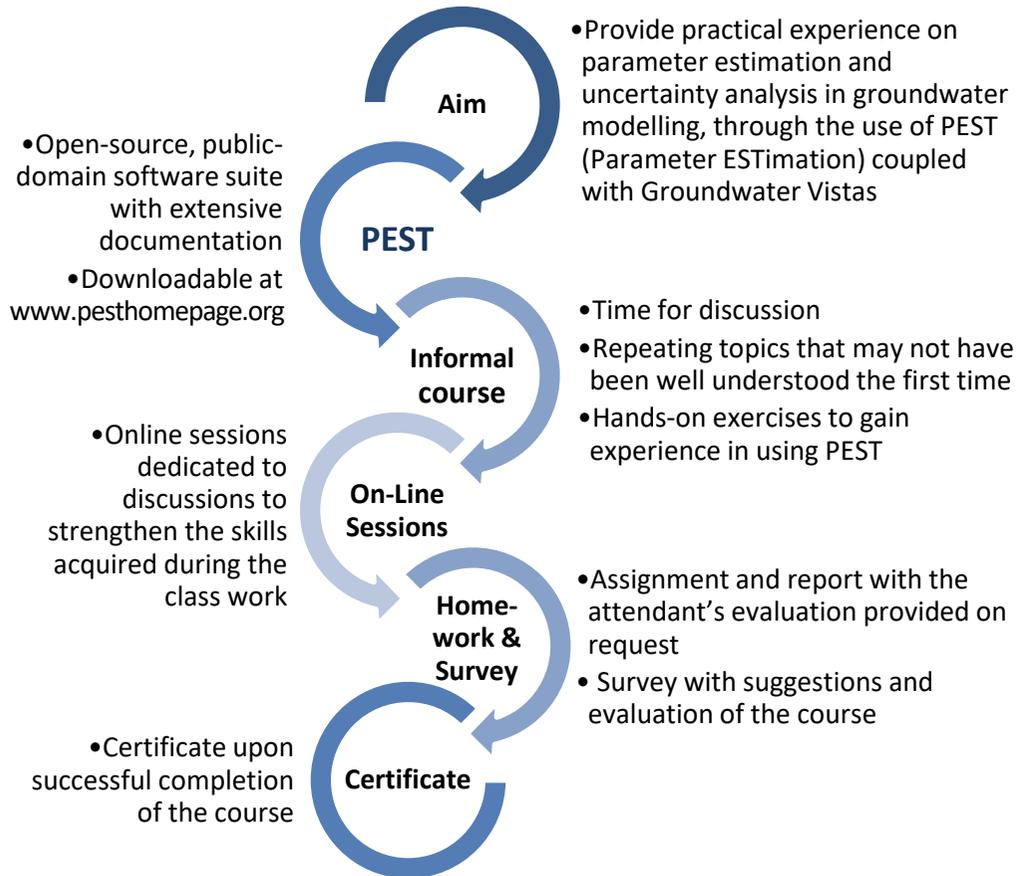
Milano  
Viale Andrea Doria, 9

24-27 September 2018

The course will grant 30 CFP (DPR 137 2012)  
for those registered with the order of the engineers.

Initiative with the recognition of the  
International Association of Hydrogeologists (IAH)

## THE COURSE



### Prerequisites

Basic knowledge of groundwater numerical modelling. Optionally, a basic understanding of matrices and vectors, statistics, geostatistics would be useful, but not essential.

Knowledge of groundwater modelling GUIs is also welcome. A temporary license of Groundwater Vistas 7 will be provided to be used in some of the hands-on exercises.

## INSTRUCTORS



**John Doherty** is the author of PEST and its supporting utility software suites.

He is a self-employed consultant, but has also held positions with the National Centre for Groundwater Research and Training, Flinders University, Australia, and with University of Queensland, where he has undertaken research and supervised PhD students. He started his career as an exploration geophysicist, but then moved to environmental modelling. He has since worked in the government, private and tertiary sectors. His research interests include the continued development of software and methodologies for solution of inverse problems using environmental models, quantification of model predictive uncertainty, and appropriate use of models in the decision-making context.



**Francesca Lotti** is a consultant hydrogeologist and partner at Kataclima srl. She has 17 years of experience in field investigations and numerical modelling of contaminated sites, mines, geothermal systems, etc. She collaborates with research institutions and international companies. She is adjunct professor at the University of Camerino, supervisor of many students/PhD/interns, trainer at professional courses and lecturer at II level Masters.



**Giovanni Formentin** is an environmental engineer and partner at Tethys srl. He has been working for 17 years as a consultant and researcher in the fields of hydrogeology and water management. He applies groundwater flow and transport models to water resources management and remediation of contaminated sites, in Italy and abroad.

## COURSE PROGRAMME

### DAY 1 – Sept. 24

#### Course presentation

- Introduction of the course
- Who are you and why are you attending?

#### S1-2: Review of fundamental concepts

- Flow equation (where everything starts from)
- Pumping test interpretation (how can it help in a model?)
- Analysis and processing of hydrogeological dataset (to become sounding model targets)
- Semivariogram (exercise with Excel)
- Regionalization of field data (exercise)
- Finite difference solution (exercise with Excel)
- Introduction to MODFLOW-USG and the CVFD solution

#### S3: Case study – Numerically enhanced conceptual modelling

#### S4: Overview of calibration and uncertainty analysis using PEST

- Metrics of a "good model"
- What is calibration?
- Modelling for decision-making
- The need to assess risk
- What should be expected of a model and what should not be expected
- Overview of PEST capabilities
- Overview of PEST++ capabilities
- Some real-world examples

### DAY 2 – Sept. 25

#### S1: Getting familiar with the command line

- The command line... why we still need it
- Windows settings to make things easier
- Execution of general tasks through the prompt line (exercise to check the proper settings of participants' computers and do a little practice)

#### S2: Waiting for PEST...

- Structure of some Modflow input/output files
- PEST input/output files
- Executable files... "Seek, and ye shall find"
- Hybrid use of PEST

#### S3: Traditional Parameter Estimation

- Well-posed inverse problem
- The Jacobian matrix – why it is needed and how to calculate it
- How to define an objective function
- How to reduce an objective function
- Observation weights
- Prior information
- Parameter transformations
- Post-calibration parameter uncertainty
- Some important PEST settings
- Serial PEST and Parallel PEST
- BEOPEST and PEST\_HP
- Dealing with problematical models

#### S4: Workshop (GUI + cmd) PEST, BeoPEST and PEST\_HP settings

A model is given, participants will have to set up PEST through the GUI, make a small change to the PEST control file and run PEST from the command line. Parameters to be calibrated will be hydraulic conductivity zones. The same PEST file will be run using BeoPEST in parallelized mode. Aim of the workshop is to make the participants feel comfortable with the command line, while doing useful tasks.

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*DAY 3 – Sept. 26*

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***S1: Highly parameterized inversion***

- Why do we need regularisation
- Subspace regularisation – singular value decomposition
- Tikhonov regularization
- Measurement and regularization objective functions
- Pilot points as a spatial parameterization device
- Optimal pilot point emplacement
- Pilot points and geostatistical regularization
- Covariance matrices as a regularization device
- Saving model runs with SVD-Assist
- Parameter identifiability
- The resolution matrix

***S2: Calibration of groundwater models – some practicalities***

- Steps to ensuring good finite-difference derivatives
- Detecting problematical finite-difference derivatives
- PEST groundwater utilities
- The PLPROC utility
- Defense against model defects
- Incorporating temporal and spatial differences into the objective function

***S3 Case study with PP calibration***

***S4: Workshop (GUI + cmd): PEST Calibration with Pilot Points***

In this workshop, participants will calibrate the model of the previous workshop using pilot points. PP will be added and modified through the GUI, and strategies for efficient use of pilot points in groundwater model calibration will be discussed. The calibration process will be accelerated by doing model runs in parallel using BeoPEST. Tikhonov regularisation, singular value decomposition and SVD-Assist will be demonstrated.

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*DAY 4 – Sept. 27*

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***S1: Introduction to uncertainty analysis***

- Uncertainty analysis and sensitivity analysis
- Basic statistics – the variogram
- Multiple point geostatistics
- Some other modern geostatistical methodologies
- Predictive uncertainty and spatial parameterization detail
- Monte Carlo methods

***S2: Calibration-constrained uncertainty analysis***

- Statement of the problem
- Linear uncertainty analysis
- Nonlinear uncertainty analysis (calibration-constrained Monte Carlo)
- Null space Monte Carlo
- Ensemble Kalman smoother
- Direct hypothesis testing

***S3 Case study – application of uncertainty analysis***

***S4: Workshop (GUI + cmd) Uncertainty analysis with Null Space Monte Carlo***

The calibrated model of the previous workshop will be used to generate a small number of realizations (i.e. 10 calibrated version of the model, but the same method would apply to 1000). Most of the uncertainty analysis will take place in the command line environment. The purpose of the exercise is to understand the importance of the uncertainty analysis, especially when the modelling is done to support decisions that must be informed about what is known and what is not known.

## Post-Course On-line Sessions

*Optional - days and hours will be agreed with interested participants*

On-line sessions will be held through an e-learning platform and will be provided after a few days of "ideas settlement". Instructions for the access to the platform will be provided during the last course session. On-line sessions can be recorded and available at a later time.

### OL1: Q&A session

- During this session participants can ask questions about difficulties encountered in performing the exercises during the workshop sessions.

### OL2: PEST suggestions and tips

- Participants will have the chance to take an individual meeting (about 2 h) with the course leaders and ask suggestions about the optimal PEST use for any specific project. A preliminary email explaining the problem is recommended.

## General Info

### Laptop requirement

All attendees should bring their own laptop computers (please specify in advance if you have a Mac OS). Software will be installed in a few minutes during the first workshop session.

### Daily course schedule

Dates: 24 - 27 September 2018

- Morning - Session 1: 09:00 – 11:00
- Morning - Session 2: 11:00 – 13:00
- Afternoon - Session 3: 14:00 – 16:00
- Afternoon - Session 4: 16:00 – 18:00

### Language

The language of the course will be English (J. Doherty) with support in Italian, and Italian/English (G. Formentin and F. Lotti).

## REGISTRATION

### REGISTRATION FEES

**Places are limited, please register quickly!**

Participant	Early Registration <i>(until AUGUST 3<sup>rd</sup>)</i>	Regular price
<i>Student (Msc, PhD)</i>	770.00 € + VAT 22%	890.00 € + VAT 22%
<i>ECHN Member*</i>	770.00 € + VAT 22%	890.00 € + VAT 22%
<i>IAH Member*</i>	890.00 € + VAT 22%	990.00 € + VAT 22%
<i>OIM Member</i>	890.00 € + VAT 22%	990.00 € + VAT 22%
<i>Regular price</i>	980.00 € + VAT 22%	1100.00 € + VAT 22%

\*If you want to take this opportunity and **join IAH**, become a member [here](#) ➔

## CONTACTS

To register and for any logistic enquiry, please write an email to:

[f.spampinato@foim.org](mailto:f.spampinato@foim.org)

For any question about the course contents, please write us at: [pest2018@tethys.srl](mailto:pest2018@tethys.srl) or send a message to

+39.338.4624787 (F. Lotti)  
+39.349.4173798 (G. Formentin)

## VENUE

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